

Modeling and Analysis of Target Echo and Clutter in Range-Dependent Bistatic Environments: FY14 Annual Report for ONR

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Award Number: N00014-11-1-0476
<http://www.onr.navy.mil/en/Science-Technology/Departments/Code-32.aspx>

LONG-TERM GOALS

The long-term goal of this work is to better understand and model reverberation, target echo, and clutter in shallow water environments, and to develop techniques for Rapid Environmental Assessment (REA) and environmentally adaptive sonar.

OBJECTIVES

The current project was a joint collaboration between Defence Research & Development Canada – Atlantic (DRDC Atlantic) and the Applied Research Laboratory of The Pennsylvania State University (ARL/PSU) to analyze and model reverberation, target echo, and clutter data in shallow water. It allowed the Principal Investigator (PI) to spend approximately two months each year at ARL/PSU. The collaboration leveraged programs in Canada and the US, and joint research projects with the NATO Centre for Maritime Research and Experimentation (CMRE) [formerly known as NATO Undersea Research Centre (NURC)]. The primary effort was analysis and interpretation of data, together with development and validation of improved modeling algorithms.

APPROACH

The PI spent two months per year at ARL/PSU, conducting joint research primarily with Dr. John Preston and Dr. Charles Holland. Additional collaboration took place throughout the year. The main objective of this collaboration was to analyze, model, and interpret data received on towed arrays during reverberation and clutter sea trials. The primary outputs of the collaboration were manuscripts for joint publications in conference proceedings and refereed journals. Secondary outputs were improved models and algorithms.

Foci of this collaboration have been Joint Research Projects (JRPs) between CMRE, Canada and several US research laboratories (ARL in particular). The JRP “Characterizing and Reducing Clutter for Broadband Active Sonar” is now complete. In the last two years the focus has been on experiment design and data analysis for the ONR “fixed-fixed” mid-frequency reverberation and target echo experiments (GulfEx12 and TREX13) in the Gulf of Mexico near Panama City, Florida [TH12, HT14].

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 2014		2. REPORT TYPE		3. DATES COVERED 00-00-2014 to 00-00-2014	
4. TITLE AND SUBTITLE Modeling and Analysis of Target Echo and Clutter in Range-Dependent Bistatic Environments: FY14 Annual Report for ONR				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Dale D. Ellis,18 Hugh Allen Drive,Dartmouth, NS, Canada B2W 2K8,				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 12	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Collaborations have been initiated with scientists at Applied Physics Laboratory, University of Washington (APL/UW).

Model development to support experiment design and data interpretation were a major focus of the work. Recent work by the PI has focused on bistatic range-dependent reverberation modeling and target echo calculations. A bistatic range-dependent “Clutter Model” [EP11, EPB12] based on adiabatic normal modes has been developed, and comparisons made with towed array data. The early comparisons were with data from the Malta Plateau, but in support of the GulfEx12 and TREX13 experiments, the model was extended to handle towed arrays with triplet elements, and predictions of reverberation and target echo made [EPB12, EP13b, EP13a, EYPP14].

WORK COMPLETED

The focus of the FY14 work has been the analysis and modeling of the reverberation and target echo data from the TREX13 experiment. The data from the GulfEx12 experiment had suggested a correlation of reverberation with sand dunes [EP13a], and preliminary analysis during the TREX13 sea trial had indicated a correlation of the reverberation peaks with the troughs of the sand dunes rather than the crests. More careful analysis was done post-trial, and indeed that turned out to be the case [EYPP14, PET14]; more details are given in the “Results” section below. As part of the analysis, predictions were made along the reverberation track with an adiabatic normal mode reverberation model. These showed correlation of reverberation peaks with the crests of the sand dunes – as expected – but opposite to the data; more details are given in the “Results” section below.

Work was done to determine the calibrations of the FORA beamforming and matched filter output. Some notes are in the PI’s presentation at the December 2013 TREX Workshop, but there are still differences between the ARL and APL processing that need to be resolved.

The Clutter Model has a target echo feature that incorporates the effect of towed array beam patterns. The predicted smearing across beams is observed in the data. Additional work on the target echo will be a component of future work.

Over the past few years, the ONR Reverberation Modeling Workshops [PT07, TP08, PT09] have been a focus for collaboration. Extensive comparisons were made between energy-flux, normal mode, ray-based models, and analytical approaches for the Pekeris model with Lambert bottom scattering; the results had been presented previously [AEH11], and after many delays a journal paper has been accepted [AEH14].

This was a transition year for the PI. After the Fall 2013 two-month visit to ARL/PSU, a short trip to APL/UW, and participation in the TREX Workshop in San Francisco, he retired from DRDC in December 2013. He continues to remain active, and involved in the TREX analysis. He was appointed adjunct professor in the Department of Physics at Mount Allison University, and in the Department of Oceanography at Dalhousie University. He co-organized a Structured Session and presented an invited paper [EYPP14] at the 2nd Underwater Acoustics Conference in Rhodes, Greece. He will be presenting an invited paper [Ell14] at the Acoustical Society of America in October 2014 and attending the follow-on TREX Workshop.

RESULTS

The most significant result for the year was the confirmation of the counterintuitive result that the reverberation peaks observed in the TREX experiment are correlated with the troughs of the sand dunes rather than the crests [EYPP14]. This section illustrates some of these results.

TREX was a series of Target and Reverberation Experiments sponsored by the US Office of Naval Research (ONR) in the Gulf of Mexico just off Panama City, Florida, US. Their unique feature was a fixed source and fixed receiver deployed in about 20 m of water, with the acoustic experiments being complemented by an extensive set of environmental measurements to facilitate the understanding of the underlying reverberation and clutter mechanisms, and to support quantitative modelling. The experiments were organized by APL/UW. An overview of the experiment is summarized by Tang and Hefner [TH12, HT14]. Preston [Pre13] has presented an overview of the some of the data.

The main experiment was conducted in April and May 2013, with the fixed source (ITC 2015) and receiver (the triplet section of the Five Octave Research Array FORA [BP03]) deployed from RV Sharp. In addition, Defence Research & Development Canada (DRDC) participated with their research vessel CFAV Quest, towing an echo repeater for transmission loss and target echo measurements, as well as continuous active sonar experiments [MHD14]. Other equipment was deployed, including the Scripps vertical line arrays for transmission loss measurements, and a DRDC passive acoustic target (PAT) for echo measurements from a fixed location. Other environmental measurements were made as well. Figure 1 shows the bathymetry and some clutter objects near the experiment site.

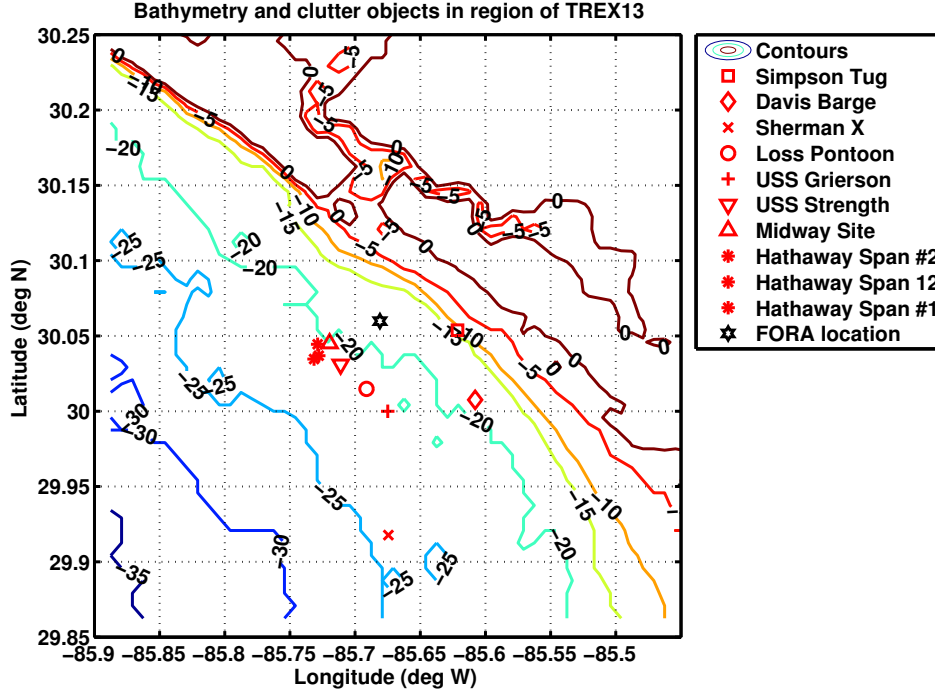


Figure 1: Bathymetry and clutter objects near the experiment. The contours (in m) are from the GEBCO_08 gridded database, contoured using Matlab. The source/receiver location is indicated by the black star. The reverberation and clutter tracks are at bearings 129° and 240° from it.

Various pulses in the 1800–3600 Hz band were sent from the ITC 2015 source, received on the FORA array, beamformed and match filtered. Reverberation data were taken during day and night, allowing study of reverberation variation over time and sea surface conditions. The FORA triplet array was used to form beams in the full 360° azimuth, allowing the directional dependence of the reverberation to be determined. Figure 2 shows a polar plot of the normalized, averaged, match-filtered reverberation for a number of the 2600–2800 Hz LFM pulses from Run 44. In this case FORA was deployed at bearing 219°, so broadside beam 118 points down the reverberation track, and beam 40 in the opposite direction. Note the north-south striations in the data to the west and southeast of the array. Particular attention was directed to reverberation returning from a track of relatively uniform water depth, extending about 10 km to the southeast of the source and receiver.

Sand dunes, and their migration, are known in this area [Kd10], so a number of bathymetric surveys were conducted. Figure 2 includes one conducted by de Moustier and colleagues before the experiment. A correlation between the reverberation and the sand dunes had been noticed previously [EP13a] in the 2012 data, but not averaged or carefully compared with the bathymetry. In the 2013 experiments it was observed that the higher reverberation levels corresponded more often with the troughs of the sand dunes, rather than the crests.

A normal-mode reverberation model is used, not to provide accurate predictions, but to provide insight into understanding the data. The Clutter Model can calculate reverberation and target echo on a towed array in bistatic geometry for a range-dependent environment [El195, EPHY08, EP11]. It uses adiabatic normal modes for propagation, ray-mode analogies for scattering, and calculates the time series of reverberation, echo, and clutter, for all all beams over an area. Calculations have been presented in previous papers as part of planning for the TREX experiments [EP11, EPB12, EP13a].

Figure 3 shows a section of polar plot of model-data differences at short distances along the reverberation track. The data are from the 1800–2700 Hz pulses from Run 82; the Clutter Model prediction is at 2250 Hz for a flat bottom; some of the bathymetric contours overlaid. Other than at very short times, the low scattering seems to be coming from the crests of the dunes (white contours), and the high scattering from the troughs (dark contours). This seems somewhat counterintuitive.

To get more insight we use a simpler model called R2D3 [EP12], which performs more detailed calculations for monostatic geometry along a single radial. To see if the reverberation levels were quantitatively reasonable they were compared with a model prediction. The key model inputs for the calculation were: isovelocity water column with sound speed 1530 m/s, and Thorp volume absorption; bottom halfspace with sound speed 1680 m/s, relative density 2.08, and attenuation 1.0 dB/m-kHz; bottom scattering with Lambert coefficient of -27 dB. Two bottom profiles were used: (1) flat bathymetry, with water depth of 18.5 m; and (2) an approximation to the bathymetry along the reverberation track at 10 m spacings.

Figure 4 (upper) shows a comparison of the range-dependent R2D3 model with some Run 17 data, a 10-ping average in the 3400–3500 Hz band. The model was run at 3450 Hz with energy source level ESL of 198.4 dB; the omnidirectional results were reduced by the effective reverberation response [EP09] of 19.7 dB. The predicted reverberation is about the correct level, although a slower drop off at short ranges and faster drop off at long ranges would be better. (A few variations on the input parameters were tried; e.g., doubling the bottom attenuation, and reducing the sound speed to 1600 m/s. These did not seem to improve the model-data agreement). These model-data comparisons are not meant to be definitive in any way; rather, they are a rapid environmental assessment tool [EP09] to

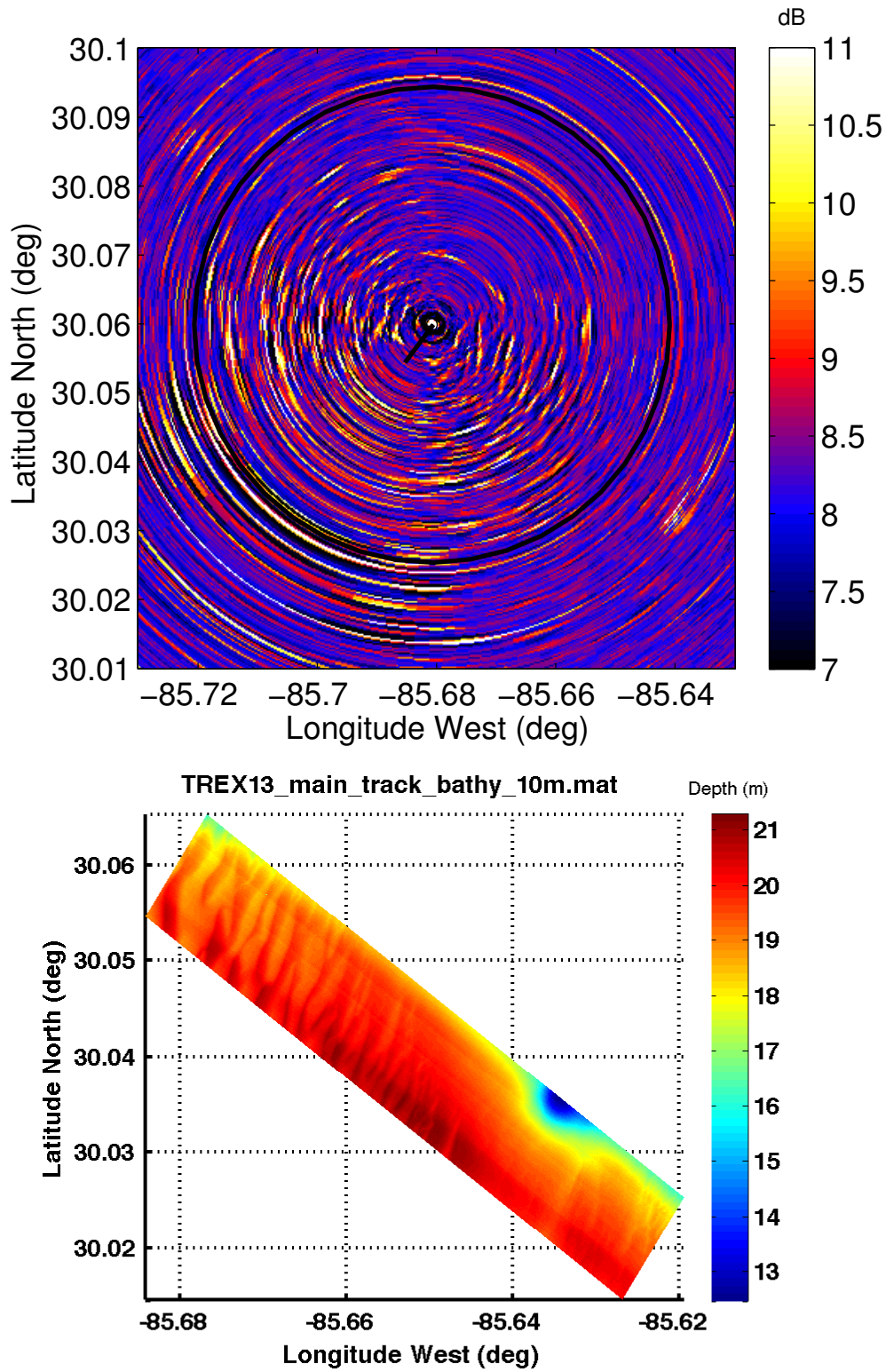


Figure 2: (Upper) Polar plot of reverberation for 2600–2800 Hz LFM pulse from Run 44 with DRDC processing, averaged and normalized by Mathieu Colin from TNO; the black circle marks 5 s. (Lower) Multibeam survey over a 1.3 by 7 km track, showing sand dunes 1–2 m in height, several hundred meters apart; the source/receiver were located midway on the NW side of the box.

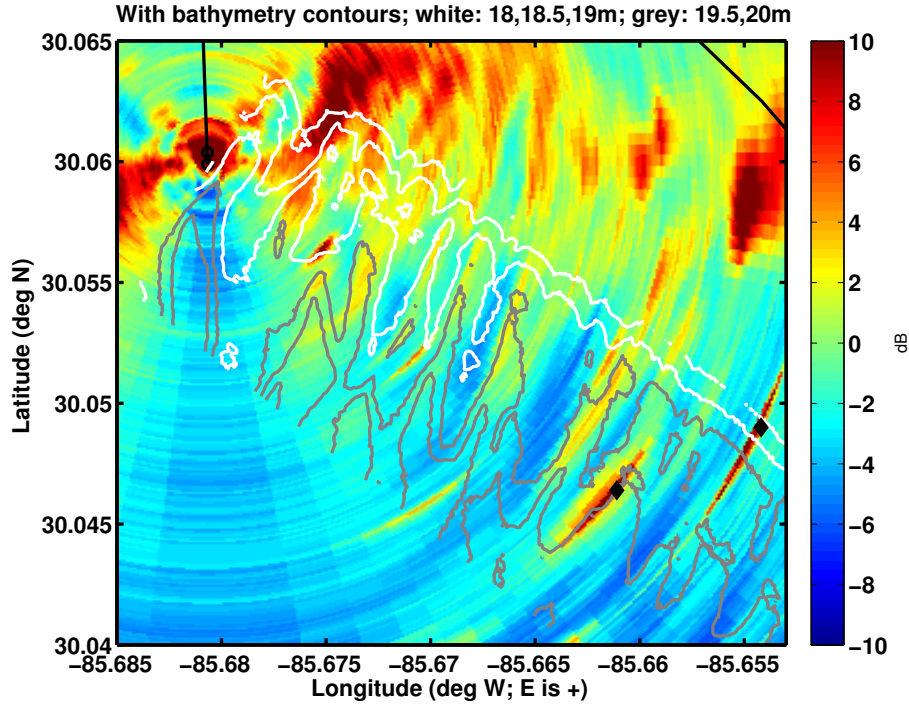


Figure 3: Polar plot of model-data differences at short ranges. The low scattering seems to be coming from the peaks of the dunes (white contours), and the high scattering from the troughs (dark contours) — somewhat counterintuitive. The echos from the VLA and PAT (black diamonds) are quite noticeable.

determine where we should concentrate for more data analysis and improved environmental inputs. Similar graphs (not shown) were obtained for the 1900–2000 Hz LFM and 2700–2800 Hz LFM, using ESLs of 195.1 and 196.8 dB, and effective reverberation response of 17.2 and 18.7 dB respectively. These account for most of the frequency dependence in the data. The bottom reflectivity for a half space is frequency independent, and the Lambert coefficient was frequency independent, so it suggests the scattering itself is not strongly frequency dependent.

Note that at short range the data shows much higher variations (~ 10 dB) than the model prediction (~ 1 – 2 dB). First we look at the model predictions. Figure 4 (lower) shows the the flat-bottom model prediction subtracted from the range-dependent model prediction; also shown is input bathymetric profile (offset by 20 m). As the water gets shallower, the reverberation increases. This what we would expect. (The model takes into consideration the bottom slope; however it is negligible, the order of 0.5 m in 150 m, or about 0.2° .)

The data, as we have seen (Fig. 3), shows the opposite behaviour with respect to the bathymetry. Figure 5 compares the reverberation variations – data minus the flat-bottom model prediction – (black) vs the bathymetric profile (red) and the slope (green) of the bathymetry. Note that the depth (red) is positive here, so that the peaks in the reverberation (black) roughly correspond to the dips in the bathymetry – a counter-intuitive result. The upper graph is from the first deployment of the source and receiver, with FORA near the start point of the reverberation track. The data are from Run 17 (10-ping average of the 3400–3500 LFM processed at APL); the model is as described earlier for Fig. 4. The lower graph is from the third deployment of FORA, about 50 m west of the start of the reverberation track. The data

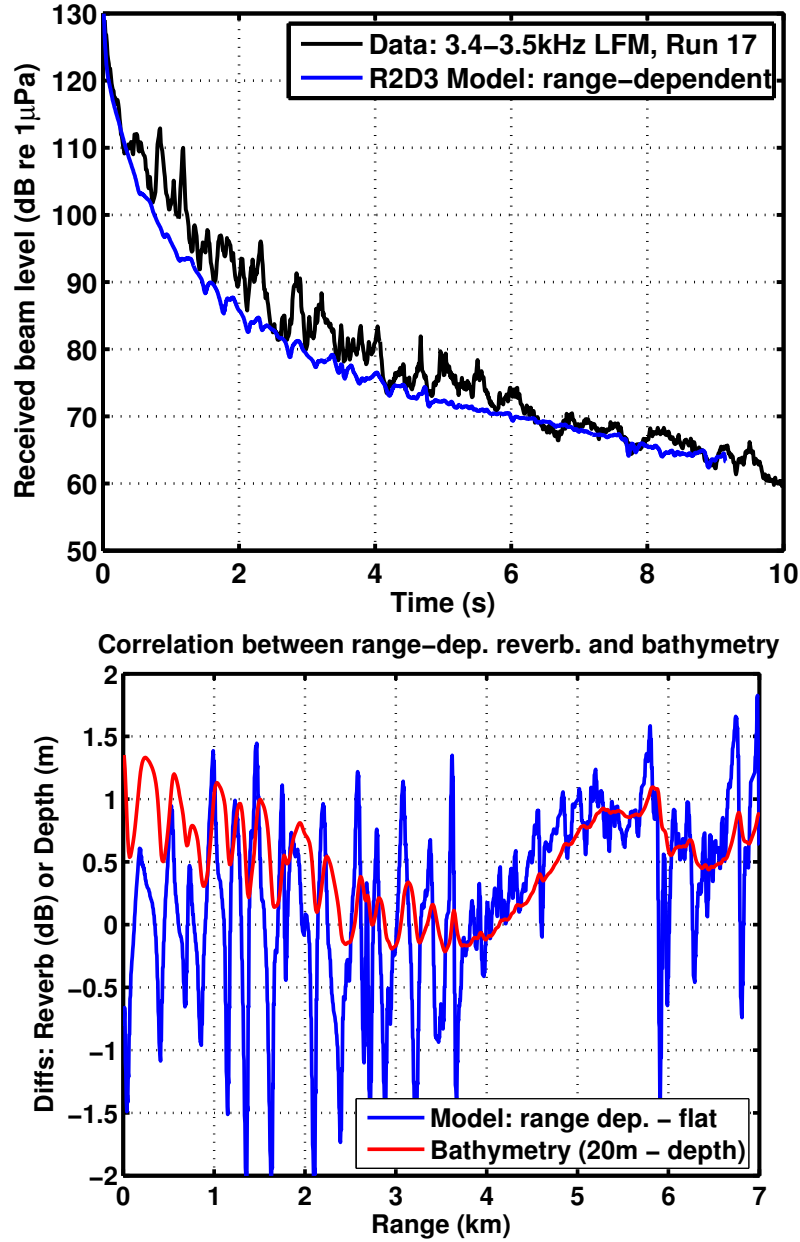


Figure 4: (Upper) Model-data reverberation comparison along main track using adiabatic normal-mode model R2D3. (Lower) Comparison of bottom bathymetry profile with differences between range-dependent and flat-bottom model predictions. Range and time related using $c_w=1530$ m/s.

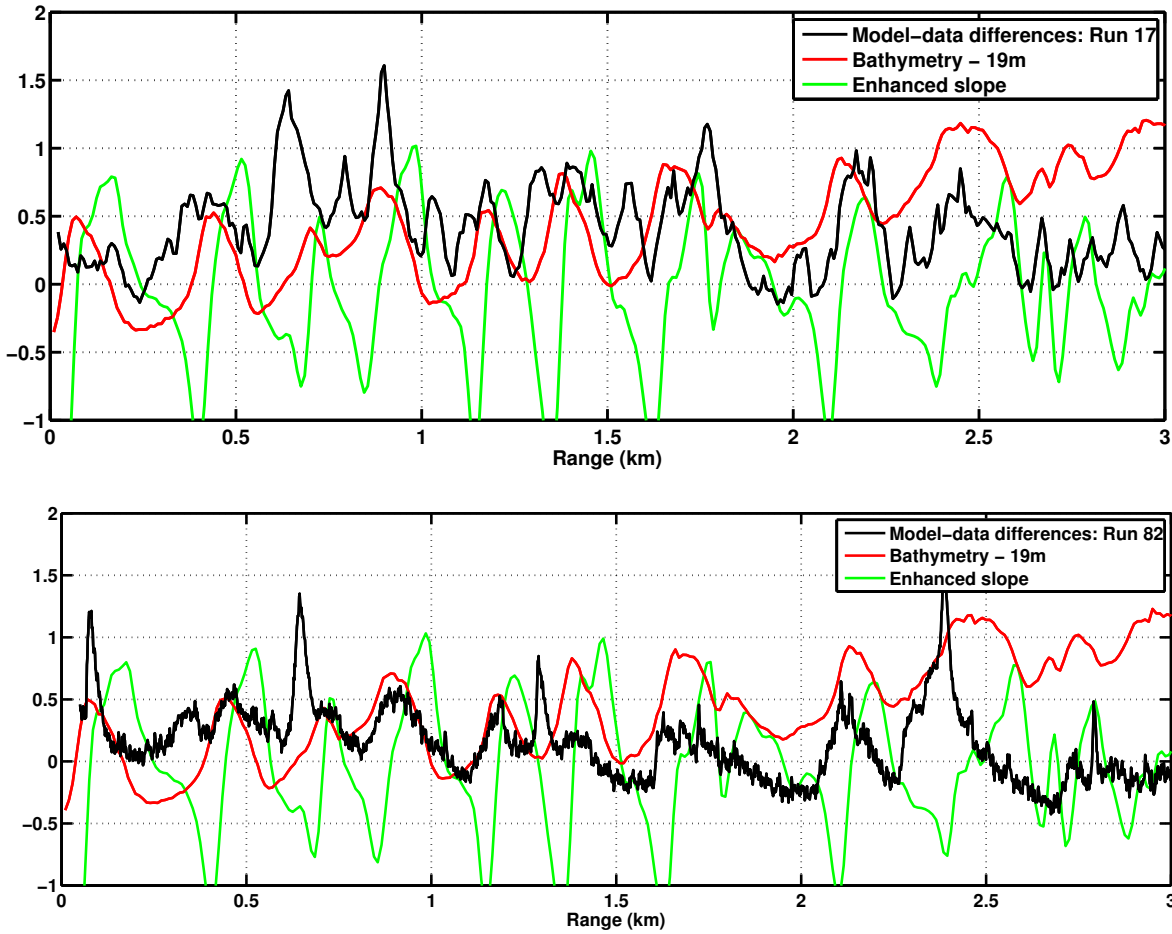


Figure 5: Correlation between the averaged reverberation along the main track, the bathymetry, and the slope of the bathymetry for Run 17 (upper) and Run 82 (lower). The bathymetric profile is from the acoustic centre of the FORA array toward the 7 km point of the reverberation track, and offset by 19 m for display. The slope (upward being positive) is increased by a factor of 100. The model-data differences in dB are reduced by a factor of 10.

are from Run 82, the 1900–2700 Hz LFM processed by the DRDC system (uncalibrated). The model calculation was at 2250 Hz, with similar environmental inputs, and with the mean level adjusted to approximate the correlated data.

Though not perfect, there is definitely a correlation between the peaks of the measured reverberation and the troughs in the bathymetry. Fluctuations, and side lobes will likely have some effect. The correlation with the slope is not as good. The explanation for the reverberation variations is likely related to the seabed or sub-bottom effects. This points to the need for additional measurements, especially in the trough regions, since that is where the measured reverberation levels are higher than the canonical -27 dB Lambert coefficient which approximates the bottom envelope of the reverberation at short ranges in Fig. 4 (upper plot).

IMPACT/APPLICATIONS

The TREX reverberation track had been chosen to be flat and uniform in order to facilitate modelling. However, one of the striking features was the correlation of the reverberation features with the sand waves (or dunes) in the area. Although only about 1 m peak-to-trough over several hundred meters range, they resulted in reverberation fluctuations on the order of 10 dB. A key observation is that the peaks in the reverberation seem to be correlated with the *troughs* of the sand dunes, rather than the crests of the sand dunes as one would expect. The simple model predicts the opposite behaviour, and smaller peaks. So this means there is some interesting physics to be explored. The explanation is likely related to the bottom or sub-bottom effects. Extensive bottom, sub-bottom, and other environmental measurements have been made along this track; these are being investigated by other researchers to facilitate understanding of the reverberation mechanisms, which was indeed the purpose of the TREX experiment. Improved models which include this new understanding will need to be developed.

From an operational perspective, clutter is viewed as one of the most important problems facing active sonar in shallow water. The long-term objective of this work is to better understand and model reverberation and clutter in shallow water environments, and to develop techniques for Rapid Environmental Assessment (REA) and environmentally adaptive sonar. The work on clutter is related to the DRDC effort in auralization and continuous active sonar and co-operative work with TTCP and other ONR efforts.

One goal is to be able to use the model with real clutter data from a towed array. If the target echo model can be validated, this could be a useful method for estimating the strength of clutter features—and even targets—in multipath shallow water environments. One could subtract out the background reverberation, including range-dependent effects and known scattering features, leaving behind the unidentified clutter on a display. These unidentified features would then be investigated by other techniques to try to determine their nature.

TRANSITIONS

Small research contracts for the Clutter Model implementation were let in 2009, 2010, 2011, and 2012. A standalone version with public domain databases and a Java GUI was developed by Brooke Numerical Systems [BKTE10] in 2010, and improved in 2012 [BT12]. Further improvements were made by Akoostix Inc. in 2013, and the hope was to be able to fully integrate the Clutter Model into the DRDC System Test Bed for comparison with towed array data.

The DRDC Technical Demonstration Project AMASE (Advancing Multistatic Active Sonar Employment) could make use of many of the techniques developed under this collaborative project.

RELATED PROJECTS

Analysis of the TREX data continues in collaboration with scientists at APL/UW, ARL/PSU, TNO (Netherlands), and other US laboratories.

Additional collaboration is taking place on analysis of the continuous active sonar (CAS) experiments that took place concurrently in 2013.

This ONR project also contributed to the DRDC research program,

<http://www.drdc-rddc.gc.ca/en/science-tech.page>,

in particular the Underwater Sensing program at the Atlantic Research Centre.

As well, the personal interaction on this project facilitated additional collaborations between scientists in the various research laboratories.

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The following publications were submitted, accepted or published during the past year:

- Michael A. Ainslie, Dale D. Ellis, and Chris H. Harrison. Low frequency bottom reverberation in a Pekeris waveguide with Lambert’s rule. *J. Comp. Acoust.*, 2014. [accepted]
- Dale D. Ellis, Jie Yang, Sean Pecknold, and John R. Preston. Correlation of reverberation with bottom sand waves along the TREX reverberation track. In John S. Papadakis and Leif Bjørnø, editors, *2nd Underwater Acoustic Conference and Exhibition: Proceedings*, pages 715–722, 2014. Conference held at Island of Rhodes, Greece, 22–27 June 2014. Invited. [published]